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APPLICATION OF KINEMATIC GLOBAL POSITIONING SYSTEM TECHNOLOGY AND UNMANNED AERIAL VEHICLES FOR CREATING LARGE-SCALE TOPOGRAPHIC MAPS IN THE VIETNAM CONDITIONS

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ABSTRACT OF THESIS FOR DOCTOR OF TECHNICAL SCIENCE

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PREFACE

1. The necessity of the thesis

Large-scale topographic maps accurately and comprehensively represent the Earth's surface and are important documents used in various fields. In Vietnam, large-scale topographic maps are often created by terrestrial *in-situ* surveying methods, which are time-consuming, labor-intensive, costly, and dependent on weather conditions, and in some cases not feasible in hard-to-reach areas. Particularly, in areas of complex high mountaneous terrain, the use of terrestrial methods poses safety risks for workers. Nowadays, the Global Navigation Satellite System (GNSS) has become an important technology widely applied in many fields, especially in surveying and map-making. The application of GNSS in topographic surveying offers high accuracy with low time-consuming, labor, and costs

The Continuously Operating Reference Stations (CORS) are a new solution aiming to expand the applications of GNSS, in which the issues that were previously limited the use of GNSS have now been completely resolved. In Vietnam, since the early 1990s, GNSS technology has been applied in surveying to establish geodetic networks and some other tasks.

Unmanned Aerial Vehicle (UAV) technology is one of the solutions developed for creating large-scale topographic maps with advantages such as low cost, rapid data collection and processing, convenience in fieldwork, high accuracy, and greater safety compared to traditional terristrial surveying methods. This method can be applied to various types of terrain, operates reliably under different conditions, and provides accurate and reliable data. However, UAV technology cannot be used in areas where surveying terrain objects are obscured. Therefore, in such cases, traditional equipment like electronic total stations must be used to supplement data in obscured locations. The method of large-scale topography mapping from imagery in cases of obscured terrain has also not been fully resolved. Additionally, while Light Detection and Ranging (LiDAR) technology can remove vegetation cover, the equipment and technology are expensive, making it impractical for widespread use by production units.

In Vietnam, the number of CORS stations is still limited and primarily concentrated in urban and plain areas. Therefore, GNSS/CORS technology is less effective in mountainous regions, national border areas, coastal zones, and islands.

To improve the accuracy of large-scale topographic map measurements in the areas where the terrain is obscured by vegetation, a comprehensive theoretical and practical study considering the existing equipment used in Vietnam is needed to demonstrate the advantages of combining devices such as commercial drones, GNSS/CORS technology, and traditional surveying methods.

For the reasons mentioned above, this thesis titled "**Application of kinematic global positioning system technology and unmanned aerial vehicles for creating large-scale topographic maps in the vietnam conditions**" is necessary, timely, and highly practical.

2. Objectives

Propose a solution for synchronizing data in large-scale topographic mapping combining GNSS/CORS technology with UAV.

Address the limitations of data collected by UAV technology in areas with terrain and features covered by vegetation.

Develop a computer module for automatic processing data in updating of large-scale topographic maps combining new technology with traditional methods.

3. Methodology

The thesis was based on an inductive approach, which started from theoretical research and practical results of the technology to generalize and establish a scientific foundation and methodology for applying UAV technology and GNSS/CORS technology in large-scale mapping.

4. Subjects and scope of the study

- Unmanned Aerial Vehicle (UAV) technology and GNSS technology;
- Large-scale topographic mapping using GNSS/CORS and UAV technology.
- Surveying and experimental calculations of horziontal and vertical control network systems in the Hanoi area, Mu Cang Chai district, and the surveying fieldcamp area in the Lang Son campus of Hanoi University of Mining and Geology.

5. Research contents of the thesis

1. Overview of national and international research.
2. Propose solutions to improve the accuracy of horizontal and vertical point measurements using GNSS and UAV technology for large-scale topographic mapping in areas with vegetation cover.

3. Propose a method for synchronizing UAV, GNSS/CORS, electronic total station data, and maps in the Hanoi 1970 (HN-72) coordinate system with those in the Vietnam 2000 (VN-2000) coordinate system in the context of Vietnam

4. Develop a software module for adjusting horizontal and vertical data to enhance the accuracy of measured points in large-scale topographic mapping.

6. Thesis statements

Thesis Statement 1: Calibration of elevation measurements using GNSS technology based on interpolation with a weighted polynomial model for higher reliability compared to those without weights applied.

Thesis Statement 2: Proposal of solutions for processing GNSS/CORS data combined with traditional technology within the VN-2000 coordinate system to improve horizontal accuracy for large-scale topographic mapping, satisfying current technical requirements.

Thesis Statement 3: Proposal of algorithm and generating software modules for digital elevation models generation from UAV imagery in areas with complex terrain and vegetation cover achieving the accuracy required by the national standards for large-scale digital topographic maps.

7. Novel contributions of the thesis

1. Synchronizing GNSS/CORS data and traditional technology in large-scale topographic mapping;

2. Proposing an algorithm and building software modules for automatically merging map data combining GNSS/CORS technology with electronic total stations;

3. Developing an algorithm and software module for automatically calibrating the elevation of terrain points measured from UAV imagery in areas with vegetation cover.

8. Scientific and practical significance

Scientific Significance: The system of solutions proposed in this thesis confirms both theoretically and practically the application and integration of advanced technologies in large-scale topographic mapping.

Practical Significance: Theoretical research and software modules facilitate the actual production of large-scale topographic maps by combining current new techniques, ensuring high accuracy and economic efficiency.

9. Structure of the thesis

The thesis is presented in four chapters, along with an introduction and conclusion:

Chapter 1: Overview of GNSS and UAV technology applications in large-scale topographic mapping.

Chapter 2: Solutions for improving horizontal and vertical accuracy using GNSS/CORS technology in large-scale topographic mapping.

Chapter 3: Large-scale topographic mapping of areas with vegetation cover using UAV imagery.

Chapter 4: Experimental calculations.

CHAPTER 1
OVERVIEW OF THE APPLICATIONS OF GNSS AND UAV TECHNOLOGY IN LARGE-SCALE TOPOGRAPHIC MAPPING

1.1 Topographic maps

1.1.1 Topographic maps

A map is a small-scale image that provides a general description of a specific area on the earth surface. Using a map, we can represent geographical information, terrain, and the locations of various elements on the Earth or in other areas. With the development of information technology, digital maps have emerged and have become popular, existing alongside traditional maps. Digital maps can be displayed as images on electronic devices or printed on paper to be used like traditional maps.

1.1.2 Accuracy of topographic maps

The accuracy of topographic maps has both technical and economic significance, as it must meet work requirements while maintaining reasonable surveying and mapping costs. The accuracy of the positions of the topographic points is characterized by the mean positional error relative to the nearest geodetic control point according to Circular 68/2015/TT-BTNMT issued by the Ministry of Natural Resources and Environment in 2015.

The elevation of a topographic point is interpolated from the elevations of contour lines. These points must ensure that the mean error does not exceed 1/4 of the contour interval when the slope is less than 2 degrees; 1/3 of the contour interval when the slope is between 2 and 6 degrees; and 1/2 of the contour interval when the slope is greater than 6 degrees.

1.1.3 Technical requirements for creating large-scale topographic maps

The error of surveying control points is specified as no more than 0.2

mm in the map. For clearly visible topographic features, the error should not exceed 0.5 mm, and for less visible features, it should not exceed 0.7 mm relative to the nearest control point. According to Circular 68/2015/TT-BTNMT, the elevation of terrain representation is determined by the contour interval specified for steep terrain and the map scale used in surveying.

1.2 Global Navigation Satellite System

1.2.1. Principles of Global Navigation Satellite System

Nowadays, there are four Global Navigation Satellite Systems including the Global Satellite System (GPS), United States; GLONASS (Russia), BeiDou (China), and Galileo (European Union), as well as two regional satellite positioning systems of IRNSS/NavIC (India) and QZSS (Japan). Although these systems differ in some respects, the basic principles of positioning remain unchanged. The GNSS is a general term used to refer to systems that enable user positioning based on a constellation of satellites. These systems help determine the location of a point in space by measuring the distances between satellites and the receiving device. By measuring the propagation time of signals transmitted from multiple satellites, users can determine the position of the receiver. This process is known as spatial intersection [43, 83].

1.2.2. Structure of the GNSS Satellite Positioning System

GNSS operates based on three segments: the space segment, the control segment, and the user segment.

1.2.3. GNSS signal structure

For most satellite positioning systems, the common signal model includes Direct-Sequence Spread Spectrum (DS-SS) signals [44], which are transmitted synchronously by all satellites in the system.

1.2.3.1 Satellite Signal Transmission

GNSS signals transmitted from satellites consist of three main components: pseudo-random noise (PRN) codes, navigation information, and carrier signals. The signal transmitted from the i-th satellite is represented as follows:

$$s_T^i(t) = \sqrt{P^i} d^i(t) c^i(t) e^{j2\pi f_c^i t} \tag{1.2}$$

1.2.3.2. Signal at the receiver

When transmitted from a satellite, the GNSS signal travels through a channel by chaning amplitude, phase, frequency, and delay. These signals are affected by various sources of errors, including signal propagation through the atmosphere, relativistic effects, and multipath effects [49]. Among these, the Doppler effect plays a significant role, named after its inventor, C. Doppler.

1.2.4. Sources of error in GNSS

The distance measured by a GNSS receiver is affected by various sources of noise and error, so called a pseudorange. The general equation for the pseudorange measurement is expressed as:

$$P_r^s = \rho_r^s + \mathrm{c}(dt_r - dT^s) + I_r^s + T_r^s + \varepsilon_r^s, \tag{1.3}$$

1.2.4.1. Clock-related errors

1.2.4.2. Signal propagation errors

1.2.4.3. Systematic errors

Systematic errors include satellite orbit errors, receiver noise.

1.2.4.4. Intentional error sources

Sources of intentional errors include selective availability, jamming signals, and spoofing signals. The satellite clock correction data in navigation information has been intentionally degraded for civilian applications, reducing accuracy to around 100 meters for surface positioning [44].

1.2.4.5. Dilution of precision

A parameter that characterizes the accuracy of GNSS-based positioning is the Dilution of Precision (DOP). This factor depends on the geometric configuration of the visible satellites; the more robust the geometric configuration, the smaller the DOP value, which in turn indicates a more reliable positioning solution. The DOP factor is used to select the satellites that will be used in the position calculation process.

1.2.5. GNSS/CORS technology

In Vietnam, the project “Building a Network of Global Satellite Positioning Stations on the Territory of Vietnam” was established with 65 CORS. The central processing and control station, located in Hanoi, is responsible for managing, monitoring, receiving, processing, and distributing data from these stations.

The geographical locations of the CORS stations on the territory of Vietnam, issued along with Circular No. 03/2020/TT-BTNMT dated May 29, 2020, by the Minister of Natural Resources and Environment, are specifically distributed as shown in Figure 1.3 [13].

Figure 1.3. CORS stations on the territory of Vietnam

The construction of the satellite positioning station system will fundamentally change the infrastructure of surveying and mapping in Vietnam. The Virtual Reference Station (VRS) method has been proposed and applied to improve the accuracy and increase the distance from the base station to the survey station in real-time kinematic (RTK) GNSS measurements. In this method, the continuously operating reference stations (CORS) are connected to form a network, and the server simultaneously collects data from the actual CORS stations to calculate and create a virtual reference station that is closest to the survey station. This helps to overcome the accuracy degradation, and the time needed to resolve ambiguities caused by the distance between the base station and the survey station.

1.3 UAV photogrammetry in topographic mapping

1.3.1 Concept

A UAV is an aircraft without an onboard pilot, operated remotely via remote control. Despite the drawback of long image processing times, UAVs have become a reasonable alternative to expensive technologies like LiDAR [66, 70]. Recently, UAVs have been widely applied in surveying and topographic mapping.

1.3.2 Classification of UAVs

The classification of UAVs is based on various criteria such as size, principle of operation, range of activity, and structural characteristics. However, in Geodesy and Cartography, most UAVs used are small, low-altitude aircraft. These aircraft are typically classified based on their takeoff and landing principles, and recently, UAVs have been studied for integration with real-time kinematic GNSS to enhance the accuracy of image center positioning. Therefore, besides classification by takeoff and landing principles, UAVs can also be divided into two types based on the method of image center positioning.

1.3.3 Image Resolution Requirements in Mapping

To achieve the required accuracy for mapping according to regulations, it is necessary to calculate the flight parameters when using UAVs to obtain a spatial resolution of the images that meets the appropriate standards.

1.4 Overview of integrating UAV, GNSS/CORS, and total station in topographic mapping

1.4.1 Overview of international research

In recent years, UAVs have emerged as a technology capable of providing high spatial and temporal resolution information at a low cost. Globally, many scientists have conducted research to provide an overview of the application of this technology in surveying and mapping. In [63], the authors systematically studied the application of UAVs in topographic mapping. The experiences in operating UAV systems for mapping purposes are presented in study [56], in which the authors provided a detailed analysis regarding UAVs, the overall system components such as autopilot, ground stations, flight planning, and mission control, as well as the image processing procedure. The results demonstrated that UAVs are capable of producing maps with reliable accuracy. The authors conducted a comprehensive evaluation of the most appropriate methods for implementing cadastral mapping processes based on UAVs and discussed the advantages and disadvantages of each method.

According to [54], UAV LiDAR systems have advantages in providing extensive and uniform ground coverage across various geomorphic environments, along with higher point density and the ability to penetrate vegetation to identify points beneath the canopy. In addition to using GNSS technology to support UAVs in mapping, total stations are also employed to supplement data in cases where the other two devices are unable to collect information.

1.4.2 Overview of research in Vietnam

Currently, in Vietnam, the application of UAV technology combined with GNSS in topographic mapping as well as in some other types of maps has been initially researched and applied. In addition to using UAV and GNSS methods in thematic and 3D mapping, this technology has also been applied in the construction of topographic maps in Vietnam. The process of creating large-scale maps in Vietnam was introduced in [16] as early as 2013.

The Vietnam Institute of Geodesy and Cartography implemented the project code TNMT.2017.07.02 titled "Research on integrating virtual reference station data acquisition devices on unmanned aerial vehicles to automate the creation of large-scale topographic maps from UAV images", large-scale topographic maps at scales of 1:500, 1:1000, 1:2000, and 1:5000 has been conducted ensuring technical requirements are met according to regulations [3]

In recent years, UAVs equipped with RTK GNSS technology (UAV/RTK) have been used to improve the ability to survey and create topographic maps using UAVs. The analysis of the research results on the application of UAV, GNSS, and total station technology in topographic and thematic mapping both globally and in Vietnam shows that:

(1) The studies have provided comprehensive and systematic evaluations of the potential for using these technologies in mapping. However, they have not extensively addressed the creation of large-scale topographic maps.

(2) The research primarily focused on proposed methods for creating thematic maps and 3D maps.

(3) Some studies have applied UAVs and GNSS in creating large-scale topographic maps with various terrains. However, these studies have not addressed the combination with traditional surveying equipment, including total stations, to enhance the accuracy of the results obtained and to leverage the advantages of each method.

1.5 Research orientation of the thesis

1.5.1 Consideration of the conditions in Vietnam

The overview of research issues in Vietnam has shown that Vietnam has integrated with GNSS techonology and UAVs for mapping. The advent of the global GNSS positioning system has fundamentally changed the methods, equipment, and approach to surveying and mapping topographic areas in Vietnam.

With the global positioning system, static measurement methods, post-processed kinematic (PPK) measurements, RTK measurements, VRS, and CORS have been applied. Additionally, the introduction of the VN-2000 national coordinate system has been implemented to align with the global satellite positioning system. With significant advancements in technology in the production of UAVs integrated with global positioning systems and high-resolution digital cameras, the method of aerial photogrammetry combined with UAV technology has been widely applied and developed.

Furthermore, due to the impact of the war, there were differences in surveying and mapping equipment and products across various regions and areas in Vietnam, particularly between urban and local areas. For this reason, survey data in Vietnam have different formats due to the use of various equipment and methods at different times.

In urban areas with high construction density, the application of new technologies like GNSS/CORS and UAVs for mapping is affected. In mountainous, border, coastal, and island areas, the density and configuration of CORS are uneven and insufficient, so GNSS/CORS technology in many places needs to be calibrated based on traditional data. Vietnam has many densely forested areas, and the application of UAV aerial photography technology for mapping is significantly affected by vegetation cover. Although some methods have been proposed and researched to isolate the effects of vegetation cover and leave only natural ground survey points, particularly in UAV LiDAR technology, these methods are not yet perfect. Thus, the effects of vegetation cover on maps created using UAV technology still exist, reducing the quality of the resulting maps.

Vietnam's coordinate systems have developed over several stages. Map data before 2000 used the HN-72 coordinate system with the Gauss-Kruger projection, while current map data use the VN-2000 coordinate system with the Universal Transverse Mercator (UTM) projection. The VN-2000 coordinate system is also different from the international coordinate system, leading to difficulties in international integration in the field of topographic mapping.

1.5.2 Research directions of the thesis

The thesis is based on the following research directions:

- Investigation of the combination of data from advanced technologies (global satellite positioning system GNSS and UAVs) with traditional surveying technologies (total stations) for creating large-scale topographic maps, ensuring accuracy and economic efficiency.
- Development of algorithms and software modules for converting data and enhancing the accuracy of GNSS/CORS data for large-scale topographic mapping.
- Propose of solutions, processes, and develop software modules that integrate global satellite positioning systems GNSS and total stations with UAV imagery data in areas with vegetation cover for large-scale topographic mapping.

CHAPTER 2
SOLUTION FOR IMPROVING HORIZONTAL AND VERTICAL ACCURACY IN APPLYING GNSS/CORS TECHNOLOGY TO LARGE-SCALE TOPOGRAPHIC MAPPING

2.1 GNSS/CORS technology in large-scale topographic mapping

2.1.1 Solution for kinematic relative measurement with multiple base stations

To determine the coordinates of measured points in kinematic relative positioning, we use a combination of code and phase measurements. This provides us with a second-order difference equation between two receivers and two satellites [28]. The second-order difference equation of phase measurements is given in Equation (2.1):

$$\lambda\phi_{ru}^{kl} = -(l_r^k - l_r^l)\, x_{ru} + \lambda N_{ru}^{kl} + \varepsilon_\phi \quad (2.1)$$

The second-order difference equation for code measurements is given in Equation (2.2):

$$\rho_{ru}^{kl} = -(l_r^k - l_r^l)\, x_{ru} + \lambda N_{ru}^{kl} + \varepsilon_\mathrm{p} \quad (2.2)$$

Combining both code and phase measurements, the second-order difference equation at any given time is written as in Equation (2.3):

$$\begin{bmatrix} L_{ru}^{kl} \\ \rho_{ru}^{kl} \end{bmatrix} = \begin{bmatrix} (l_r^l - l_r^k)_{mx3} & \lambda I_{mxn} \\ (l_r^l - l_r^k)_{mx3} & 0 \end{bmatrix} \begin{bmatrix} x_{ru} \\ N_{ru}^{kl} \end{bmatrix} + \begin{bmatrix} \varepsilon_\phi \\ \varepsilon_\mathrm{p} \end{bmatrix} \quad (2.3)$$

$$L_{ru}^{kl} = \lambda_{ru}^{kl};\ \ m = n - 1;$$

where u and r are the receiver identifiers, and l and k are the satellite identifiers.

2.1.2 Measurement solution with fixed virtual referece stations

2.1.2.1 Virtual reference station technique

The VRS technique is used in RTK relative positioning solutions to provide high accuracy by creating virtual reference station data or reference stations without an operator that are only a few meters away from the RTK measurement device. The principle of this method is to interpolate data from multiple CORS reference stations to obtain the most accurate correction data for the measurement device, thus improving accuracy in RTK measurements.

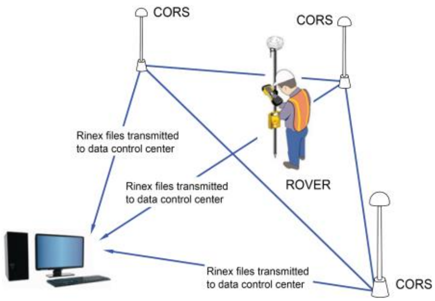
2.1.2.2 Operation principle of virtual reference stations

Step 1: Creation of corrections at the central processor

GNSS/CORS reference stations are connected to a server (central processor), and each reference station shares data to create a correction model depending on the distance. At least three CORS stations need to operate around the mobile (rover) station. The central server generates a virtual reference station (VRS) just a few meters away from the measurement device in real-time, along with correction data from the surrounding reference station network.

Step 2: Transmition of data to the rover

The data and corrections from the VRS are transmitted to the rover stations via wireless connections. Finally, the rover's receiver uses simple algorithms to determine its coordinates through the correction data and distance, as shown in Figure 2.2.



Hình 2.2. CORS network

2.1.3 Coordinate transformation of GNSS/CORS to the international terrestrial reference frame

The international terrestrial reference rrame (ITRF) is a global reference system calculated and regularly updated by international CORS reference stations, such as International GNSS Service (IGS). The process of transforming internal coordinates between ITRF reference frames or transforming coordinates between the Vietnam local coordinate system VN-2000 and the international ITRF is carried out by [11, 32]:

$$X_{(2)} = T + (1 + D)R^T X_{(1)} \qquad (2.1)$$

2.1.4 Assessment of the accuracy of GNSS/CORS measurements

2.1.4.1. Accuracy of topographic measurements using GNSS/CORS technology

To evaluate the accuracy of GNSS/CORS technology in measuring points for topographic mapping, a network of benchmarks from two projects, the Nhổn - Cát Linh line and the Âu Cơ line, along with national elevation benchmarks in the Hanoi area, covering approximately 400 km², was used.

At each control point along the lines, measurements were taken using two different systems, 1) a single CORS station and 2) a VRS.

2.1.5 Objective of combining GNSS/CORS technology with traditional technology

In large-scale topographic map creation, measured points determined by total stations remain a good choice due to their high reliability, flexibility, and effectiveness in areas with limited space, high density of measured points, and obstructions such as residential areas and vegetation cover. The kinematic GNSS technology can achieve high results and performance in open areas with a clear view of satellites. However, combining GNSS/CORS technology with traditional methods in large-scale mapping can result in shifts in both horizontal and vertical coordinates due to differences in the coordinate systems used.

Updating topographic maps involves revising, changing, and renew the map contents according to the current state. This requires reusing control points around the adjustment area, which leads to many technical and economic challenges. Based on the coordinates and elevations of control points or distinctive features on the map determined in both data systems, referred to as common points, coordinate transformation on the plane is performed for each point using weighted least squares methods to determine transformation coefficients. This allows for the conversion of measurement points to a unified coordinate system. The program module supports automatic, fast, and accurate processing of this problem. For elevation, a local geoid model is built for calibration. The geoid model is based on geometric leveling data, considering the distance from measurement points to the leveling points. For horizontal coordinates, coordinate transformation tasks are performed based on high-accuracy coordinates to standardize the coordinate data.

2.2 Transforming topographic point elevations measured by GNSS to the local vertical datum

There are many methods for interpolating height anomalies. In practice, various interpolation methods are commonly used, such as polynomial interpolation, collocation interpolation, kriging interpolation, and spline interpolation. This thesis focuses on examining the polynomial interpolation method. The interpolation is performed for each measurement point by assigning weights that are inversely proportional to the distance from the point to the common elevation points.

2.2.1 Polynomial model for height anomaly interpolation

Height anomalies are calculated using the following equation:

$$\zeta = H - h^{\gamma} \quad (2.4)$$

There is the need to transform geodetic elevation to the local vertical datum. Currently, Vietnam has not developed an accurate geoid model for the entire country and can only ensure that the vertical datum is determined with a certain level of accuracy. To improve the accuracy of elevation determination using GNSS/CORS technology for large-scale topographic mapping, it is proposed to use high-precision elevation points in the survey area and develop a local geoid model for the region.

Depending on the number of benchmark points available in the area, the elevation anomaly model ζ can be of polynomial degree 0, 1, 2, or 3. The equation for the elevation anomaly model ζi is as follows:

$$\zeta_i = F(x_i\ ,\ y_i) \quad (2.6)$$

The equation for the polynomial height anomaly model for specific degrees in a matrix form is as follows:

$$\zeta = N.X$$

$$\text{where } \zeta=\begin{bmatrix}\zeta_1\\ \zeta_2\\ \cdots\\ \zeta_n\end{bmatrix};\ N=\begin{bmatrix}x_1 & y_1 & 1\\ x_2 & y_2 & 1\\ \cdots & \cdots & \cdots\\ x_n & y_n & 1\end{bmatrix};\ X=\begin{bmatrix}a\\ b\\ \zeta o\end{bmatrix} \quad (2.7)$$

In cases where the number of coefficients is less than the number of benchmark points, we use the least squares method to calculate the coefficients.

In determining the coefficients of the local geoid model, the effect of different benchmark points on the correction for each point is weighted according to their impact. For each measurement point, the coefficients of the local geoid model are recalculated with weights that are inversely proportional to the distance from the measurement point to the benchmark points with known elevations.

The coordinates of the measurement points obtained using GNSS technology (X, Y, Z) in the international System WGS84 are converted to the horiontal coordinate system VN-2000 according to the below diagram:

$(XYZ)_{WGS84}$--->$(XYZ)_{VN\text{-}2000}$---->$(BLH)_{VN\text{-}2000}$--->$(xyh)_{VN\text{-}2000}$

2.2.2 Calculation steps and program module workflow

The workflow used for converting GNSS measurements to VN-2000 coordinates and orthometric height is performed according to the block diagram in Figure 2.6.

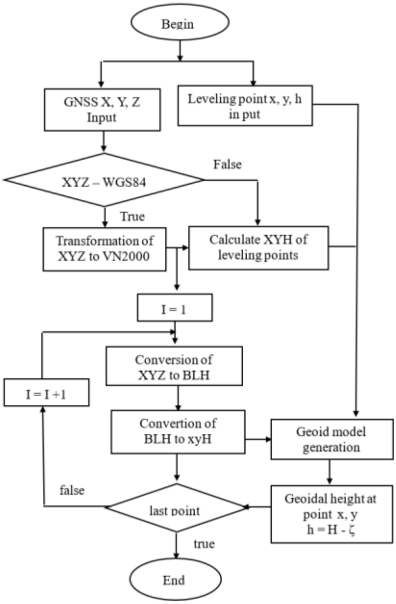


Figure 2.6. Workflow of the program module for transforming GNSS measurements to VN-2000 coordinates and orthometric height

2.3 Transformation of coordinates measured by GNSS/CORS technology

2.3.1 Algorithm for horizontal coordinates transformation

The problem of horizontal coordinates transformation from the first system $(xoy)_1$ to the second system $(xoy)_2$ is performed within a small area (on a plane) using the following transformations [8],[9]: Helmert transformation, Affine transformation, polynomial transformation of degrees 2 or 3.

2.3.2. Weighted problem in horizontal coordinate transformation and geoid model

According to the equations used in horizontal coordinate transformation and local geoid modeling, it is necessary to determine coefficients based on the coordinates and elevations of the reference points.

When the number of coordinates and reference elevations used exceeds the number of unknowns to be determined, the problem is solved using least squares adjustment. The coefficients determined this way are the most reliable; however, the original data values obtained after conversion through these coefficients may deviate from the initial values. This deviation depends on the number and distribution of the original data, and the resulting values may not be convincing.

To address this issue, weights are introduced into the problem. In the weighted problem, for each point, we re-determine the coefficients, and the weighted correction equations P are inversely proportional to the distance or the square of the distance from the measurement point to the reference points. The weight P is chosen during the calculation. In the weighted processing problem, each measurement point to be adjusted is treated, with each point having different distances to the reference points (resulting in different weights P). The coefficients obtained will approximate the initial values for the reference points (overlapping points). The processed data for other points will be adjusted based on the reference points within a small area (local adjustments according to the reference data).

2.3.3. Accuracy of GNSS/CORS measurements when combined with horizontal and vertical control points

The accuracy of GNSS/CORS measurements is inconsistent, depending on the measurement method (PPK, RTK, VRS), the location of the survey area, and the CORS station network configuration. The accuracy of GNSS/CORS measurements is improved by combining measurement data with available coordinate data in the survey area applied to coordinate transformation.

2.4 Synchronizing large-scale topographic map data

2.4.1 Data synchronization problem

To synchronize the upted measurements with the original map, it is necessary to connect measurements to some clearly defined topographic points or existing control points in the survey area. Through the problem of coordinate transformation on a plane and geoid modeling, using a weighted approach, the transformation coefficients are determined based on the least squares principle. This allows for the conversion of coordinates and elevations of measurement points to a common coordinate system.

2.4.2 Verification of horizontal coordinates and elevations of common points

Based on the horizontal coordinates and elevations of the same test points, the distance and elevation difference between them in the two data systems are determined. The distance must be less than an allowable value, which is calculated based on the position error of the control points for the mapping scale (m_d) according to the map scale:

$$\Delta_d < (2\text{-}3).m_d.M_{bd}\sqrt{2} \quad (2.31)$$

The elevation difference accuracy is determined by the technical leveling accuracy value of 50 mm per 1 km. If the elevation differences exceed the allowable value, the accuracy of the common points needs to be rechecked.

2.4.3 Workflow for data synchronization module

The workflow of synchronizing map data in cases of calibration measurements and measurements using different technologies is outlined in Figure 2.9.

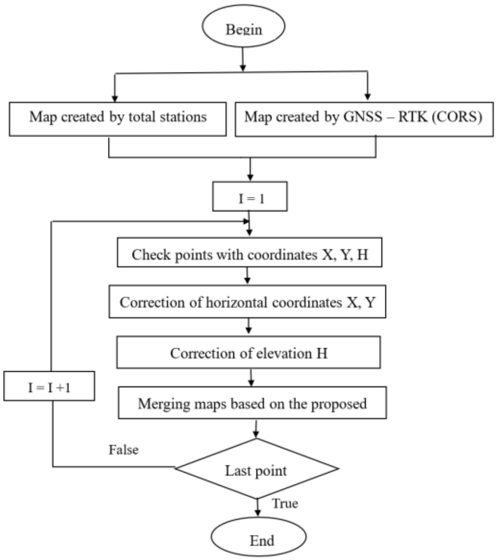


Figure 2.9: Workflow for synchronizing GNSS/CORS and electronic total station map data

CHAPTER 3
LARGE-SCALE TOPOGRAPHIC MAPPING FOR AREAS WITH VEGETATION COVER USING UAV IMAGE DATA

3.1 Introduction

This thesis proposes a solution for correcting the vegetation cover digital surface model (DSM) derived from UAV image data based on control points measured using GNSS/CORS technology in topographic mapping. An automated software tool was built that adjusts the elevation of points measured on the vegetation surface to the elevation of topographic points, demonstrating the accuracy of the algorithm.

3.2 Correcting the surface model for vegetation-covered areas using UAV data in large-scale topographic mapping

3.2.1 Ditital surface model method

The digital surface model problem has been discussed in many documents. Each method has its own scope of application depending on the advantages and disadvantages of each approach [26].

3.2.2 Correcting the digital surface model for vegetation-covered areas

In this thesis, the polynomial function problem has been applied to determine the thickness of the vegetation cover. The correction of the elevation of image points measured using UAV technology to the actual terrain elevation at each point is described as follows: The function representing the relationship between the vegetation cover and the terrain surface is expressed as:

$$Z_i = F(x_i, y_i) \qquad (3.3)$$

with Z_i is the thickness of the vegetation cover at the point with coordinates (x_i, y_i); F is the polynomial function of degree 1 to 3 depending on the terrain area. In cases where the number of control points is larger than the number of coefficients, the least squares principle is applied to find the optimal coefficients. Finally, the correction of the vegetation cover elevation to the terrain surface elevation is calculated using Equation (3.7):

$$H_{đh} = H_{DSM} - Z \qquad (3.7)$$

3.2.3. Process of correction

The process is carried out in two steps: 1) Smoothing the DSM; 2) determining the Digital Terrain Model (DTM) from the DSM.

3.2.4 Model data

To validate the results, DSM data was generated for an experimental area of approximately 1 km². A third-degree polynomial model was constructed to represent the vegetation thickness. Based on the elevation of ground points and the thickness of the vegetation layer, the DTM was determined. The results showed that the theoretical foundation and the program module are appropriate and highly reliable. The RMSE of elevation, calculated according to the actual error, is m=±0.2m.

CHAPTER 4
EXPERIMENT

4.1 GNSS/CORS accuracy assessment

4.1.1 Accuracy of GNSS RTK Measurements

In the experimental area of Cát Linh-Hà Đông, Âu Cơ, the measurements were taken using RTK technology with the Aitogy B20 receiver and processed with the Alnavi software. The accuracy results are as follows: $m_x=\pm0.042$m; $m_y=\pm0.028$m; $m_d=\pm0.050$m; $m_h=\pm0.078$m. The maximum errors observed were: $\Delta x=0.079$m, $\Delta y=0.042$m, $\Delta d=0.087$m, $\Delta h=0.136$m.

4.1.2 Accuracy of GNSS/CORS VRS measurements

For VRS technology, the horizontal coordinates and elevations were remeasured using VRS technology and compared to known reference values. The accuracy assessment data is as follows: $m_x=\pm0.014$m, $m_y=\pm0.025$m, $m_d=\pm0.029$m, $m_h=\pm0.028$m. The maximum errors observed were: $\Delta x=0.031$m, $\Delta y=0.118$m, $\Delta d=0.119$m, $\Delta h=0.069$m.

4.1.3 Comments on the accuracy of GNSS/CORS measurements (RTK and VRS)

The results indicate that the horizontal and vertical coordinate errors using kinematic GNSS measurement with a single CORS station compared to the original coordinate values are significant and of systematic errors. Specifically, the maximum horizontal error is up to 0.087 m, while the maximum vertical error is 0.136 m. Additionally, the root mean square error (RMSE), determined using the actual error equation, shows results of ± 0.050 m in the horizontal and ± 0.078 m in the vertical.

To address these systematic errors, some manufacturers have calibrated these errors by measuring several geodetic control points near the measurement area to determine the local systematic error and adjust the measurement results accordingly. The local systematic error values vary by region and can be programmed into the measurement device for user convenience and accuracy. However, this approach is only temporary, approximate, and limited in small areas.

The VRS method addresses some of the shortcomings of the single CORS station method. For the horizontal position, the maximum error is up to 0.118 m, and for the vertical position, the maximum error is 0.069 m. The RMSEs, determined using the actual error formula, are ±0.029 m for the horizontal and ±0.028 m for the vertical. With the VRS method, the accuracy has significantly improved depending on the region due to the distribution of CORS stations.

4.2 Transformation of terrain elevation measured by GNSS technology to orthometric height

4.2.1 GNSS data transformation

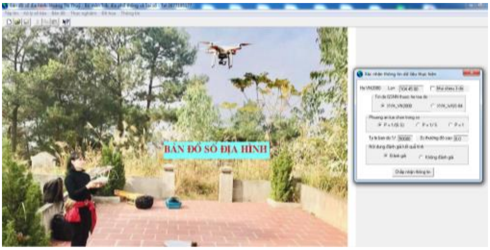


Figure 4.1 Module used to transform GNSS data to the VN-2000 coordinate system and orthometric height

4.2.2 Workflow and experimental data

The experimental area in Mù Cang Chải District, Yên Bái Province, covers 400 km². The area includes 5 national third-order elevation benchmarks and 5 national geodetic control points. Measurements were taken at 30 GPS points distributed across the study area using the Trimble 5700 and Trimble R8S equipment. The leveling data were collected using the Ni030 equipment.

4.2.3 Calculated results using the software module

Option 1: Weight selection: P=1/s.s

S T T	TEN DIEM DO	X1 Y1 (TRI DO) Z1 (XYZ)	X2 Y2 (VN2000) Z2 (XYZ)	x2 y2 (VN2000) H2(Trac_Dia)	h(TC)	h(TC_Goc)	Chenh_lech
		-1441162.2847	-1441162.2847	2415171.1282			
1	077423	5746484.0925	5746484.0925	430644.4203			
		2358410.7752	2358410.7752	1408.9848	1405.150	1405.150	0.000
		-1460685.7912	-1460685.7912	2408956.7659			
2	077432	5743315.5849	5743315.5849	450315.9563			
		2352476.7272	2352476.7272	790.5237	787.160	787.160	0.000

4.2.4 Results of transforming GNSS-based elevations to orthometric heights using weights

With a weight P=1, the estimated accuracy is [ΔΔ]= 0.0031882, n = 40, m = ± 0.056 (m)

With a weight P=1/SS, the estimated accuracy is [ΔΔ]= 0.000502375, n = 40, m = ± 0.023 (m).

Based on the corrections of GNSS-measured heights to orthometric heights, and through the original orthometric heights, we obtain a contour map and a local geoid model as shown in Figures 4.3 and 4.4.

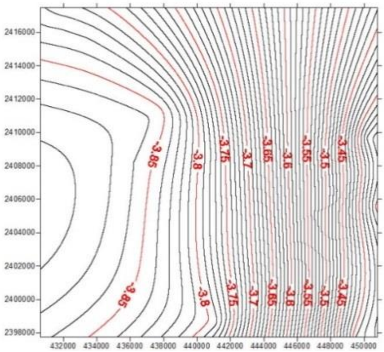


Figure 4.3. Geoidal height contour map

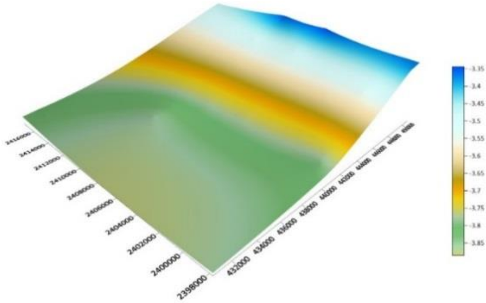


Figure 4.4 Geoidal height digital model

The results show that applying weights to the correction results in a point position error m = ±0.023m, which is smaller compared to the unweighted adjustment result m = ±0.056m. The adjusted coordinates of the reference points are close to the original values. Thus, the weighted adjustment results are more reliable and accurate.

4.3 Coordinate transformation problem for GNSS/CORS measurements

4.3.1 Module for coordinate and height transformation of GNSS/CORS measurements

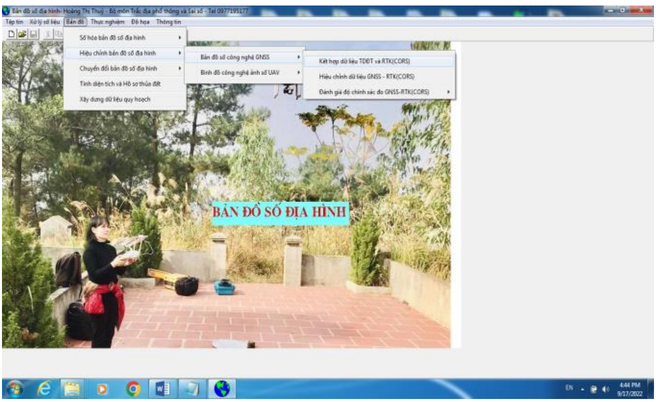


Figure 4.5: Module for horizontal coordinate and height transformation of GNSS/CORS measurement points

4.3.2 Accuracy of GNSS/CORS after correction

Calculations are performed for the experimental areas along the Cát Linh - Hà Đông and Âu Cơ Level II routes. Horizontal coordinates and elevations of the control points are considered as true values to evaluate the accuracy of the measurements and for calibration. The accuracy of RTK measurements (using a single CORS) significantly improves, while the RTK method using VRS CORS increases accuracy by 10% to 20%. For elevations, the accuracy has improved significantly with errors reduced from ±0.10 m to ±0.03 m.

4.4 Synchronizing large-scale topographic map data

4.4.1 Map data synchronization program module

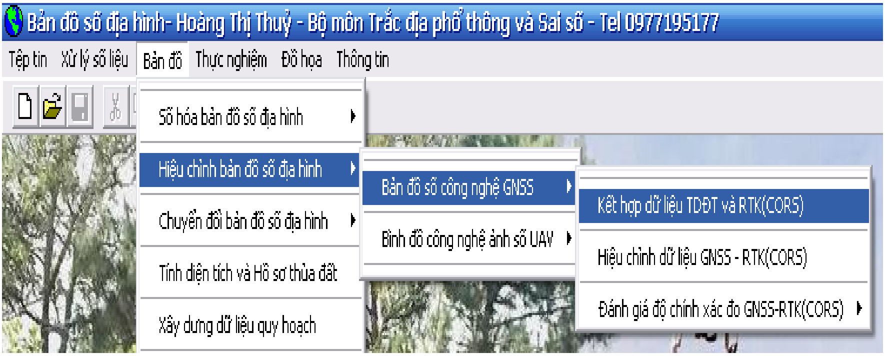


Figure 4.6 Synchronization module of map data measured using different technologies

4.4.2 Results of synchronizing map data

Implementing the map data synchronization program module, the updated measurement data and the original maps are merged. The results obtained after merging are consistent and accurate.

4.5 Calibration of surface model with vegetation cover from UAV data in large-scale topographic mapping

4.5.1 Module for smoothing the digital surface model and building the digital terrain model

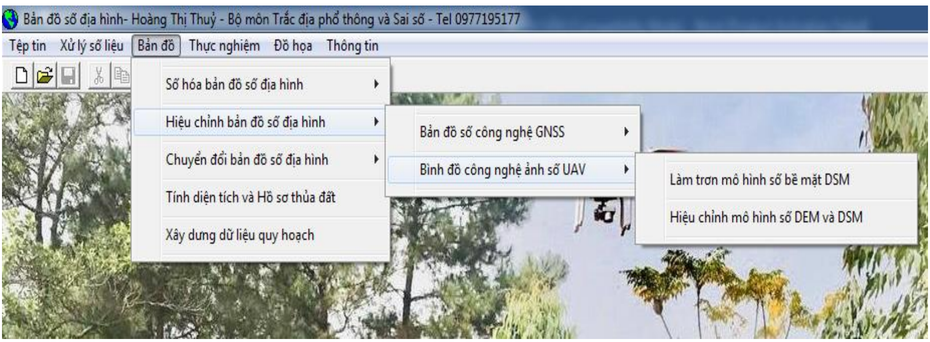


Figure 4.11. Module for smoothing the digital surface model and building the digital terrain model

4.5.2 Construction of a digital terrain model from UAV image data in areas with vegetation cover

Figure 4.16. UAV experiment in Lạng Sơn

Figure 4.21 Aerial photo taken at the Lạng Sơn experiment area

To further validate the research results, the program module was executed with the actual survey data in Lạng Sơn City using total stations to create a 1:1000 scale topographic map as shown in Figure 4.22. The UAV technology captured a DSM of the vegetation cover, as shown in Figure 4.23.

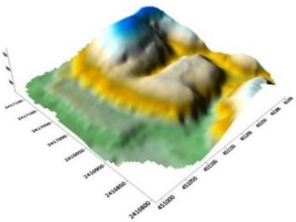


Figure 4.22 Digital terrain model from measurement data in Lạng Sơn City

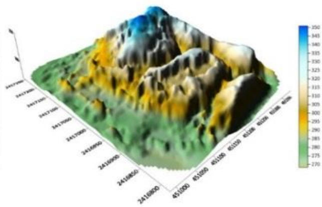


Figure 4.23 Digital surface model (DSM) of vegetation cover using UAV technology

By using the program module, the DSM model was smoothed with a smoothing radius of 50m. The created DSM is shown in Figure 4.24. The result of removing the vegetation cover using the program module is the DEM as shown in Figure 4.25.

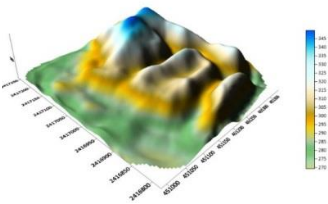


Figure 4.24. DSM model obtained after smoothing

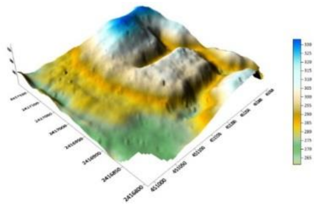


Figure 4.25 Digital terrain model obtained from DSM data for the Lạng Sơn area

CONCLUSION AND RECOMMENDATIONS

CONCLUSION

The algorithm for calculating horizontal coordinates and orthometric heights based on geoidal heights of benchmark points in the study area in applying GNSS technology to large-scale topographic mapping has significantly scientific and practical meanings. The program module has synchronized data from GNSS/CORS, UAV, and traditional technologies in topographic mapping, meeting technical requirements and achieving economic efficiency. Experimental data have shown that applying GNSS topographic measurement results combined with benchmark elevation data ensures accuracy in creating large-scale topographic maps.

The thesis has applied the weighted coordinate transformation problem to develop an automated program module for merging maps in updating, combining traditional technology with GNSS and UAV technology, which has practical significance.

The application of algorithms, processes, and program modules to create DTMs from UAV image data in vegetated areas has achieved the required accuracy for large-scale topographic maps.

The theoretical basis and experimental results indicate that the research outcomes can be effectively applied in topographic and cadastral mapping when combining data from UAV, GNSS/CORS, and total stations.

RECOMMENDATIONS

As the application of new technologies in large-scale digital topographic mapping continues to evolve, ongoing research is needed to keep pace with the relentless advancements in science and technology, particularly in the field of surveying and mapping.

GNSS/CORS technology for creating large-scale topographic maps in national border areas and islands requires further research due to the uneven distribution of CORS stations in terms of density and configuration in topographic mapping.

Further research is needed to explore the potential of UAV digital image technology for topographic mapping in areas with steep slopes and vegetation cover.

LIST OF AUTHOR'S PUBLISHED SCIENTIFIC WORKS RELATED TO CONTENTS OF THE DISSERTATION

1. Hoàng Thị Thủy, Đinh Công Hoà (2017), "Ứng dụng công nghệ RTK và máy toàn đạc điện tử trong thành lập bản đồ số tỷ lệ lớn, "Tạp chí Khoa học kỹ thuật Mỏ - Địa Chất, Tập 58 (Kỳ 6) 16-21.
2. Dương Thành Trung, Hoàng Thị Thủy, Võ Minh Tuấn (2019), "Giải pháp định vị GPS tương đối động xử lý sau với nhiều trạm cơ sở trong công tác thành lập bản đồ số tỷ lệ lớn", Tạp chí khoa học Kỹ thuật Mỏ - Địa Chất, Tập 60 (Kỳ 2) 98-105.
3. Hoàng Thị Thủy, Đinh Công Hoà (2020). "Giải pháp thành lập bản đồ địa hình từ dữ liệu UAV vùng có phủ thực vật ", Tạp chí Khoa học Đo đạc và Bản đồ, Tập 44 (Kỳ 6) 49-55.
4. Hoàng Thị Thủy (2021). "Giải pháp hiệu chỉnh tọa độ và độ cao điểm chi tiết trên bản đồ địa hình tỷ lệ lớn thành lập từ công nghệ kết hợp GNSS/CORS và toàn đạc điện tử ", Tạp chí Khoa học Đo đạc và Bản đồ,Tập 47 (kỳ 3) 13-17
5. Hoàng Thị Thủy (2023). "Xây dựng modul chương trình hỗ trợ công tác lập bản đồ quy hoạch sử dụng đất từ dữ liệu bản đồ địa hình, địa chính", Tạp chí Khoa học Đo đạc và Bản đồ, Tập 55 (kỳ 3) 55-64.